Identifying potential for fisheries-induced evolution on behavioral traits of a Skagerrak cod (*Gadus morhua*) population.

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Abstract

Fisheries activities and the development of more efficient fishing gear, have had detrimental effects in commercial stocks. This occurs largely as a result of negative selection acting on certain individuals during the harvesting process. Empirical observations show that fishing mortality and/or selective fishing pressure, leads to reductions in age and size at maturity of fish. Research shows that this is not only driven by phenotypic plasticity, but also by an evolutionary mechanism. Similarly, behavior is a trait subject to harvest selection and is subject to genetic changes at the population level. This is expected to have negative consequences derived from depletion of genotypes specialized to a particular food and habitat use. A loss of such adaptive capacity could potentially cause diminished resilience of the stock. The impact of fisheries on behavior has gained attention in the last decades but few approaches have studied wild commercial fish. The objective of the present work was to characterize the relationship between two behavioral variables related with fisheries and reproductive success to detect potential for harvest selection in behavior of Skagerrak cod. Contrary to what was expected, no relationship between the variables and reproductive success was found suggesting either, lack of potential or, poor sampling. Further experiments should consider the role of the area where the experimental fish come from and the capture methods used.

1. Introduction

1.1 Context

According to the Fish and Agriculture Organization (FAO, 2015) a fishery is a unit consisting of individuals involved in the harvesting of a particular stock (of fish, invertebrate and/or mammal) that is located in a defined area by means of one, or an arrange of fishing methods. Due to extension of fishing areas, the diversity of consumed food fish species, and the usually high population size and fertility of these, the unsustainable nature of fisheries remained long time masked. Whenever a population was depleted, fishers, would simply switch to a different location or target another species (Pauly *et al* 2002). The problem of overfishing was exacerbated with technological improvements such as the developing of bottom trawling gear and radars that industrialized fishing and made it possible to reach previously untouched stocks worldwide as well as fish even more from those that were already exploited (Pauly *et al* 2002). The new conditions lead fishers, managers and politicians to believe that increasing the fishing effort (intensity of activities and number of boats) and its efficiency (number of fish caught per unit of fishing effort) would automatically produce higher revenue (Pauly *et al* 2002).

Subsequently, and as the FAO records indicate, from the beginning of the second half of the last century landings increased dramatically. Consequences of such practices though, were swift and included a variety of effects, for example, the depletion of large predators in marine ecosystems due to "fishing down marine food web" (Pauly *et al* 1998) and fisheries collapses with global repercussions (Hutchings & Fraser 2008). Today, fisheries effects continue to be a problem and moreover, it has become clear that besides direct negative impacts on target species such as reductions in abundance and depletions, overexploitation can result in phenotypic changes in life-history traits that modify and even make stocks more prone to extinction (Hutchings & Fraser 2008).

Besides commercial fishing, recreational fishing also has an impact on fish stocks. The impact of this kind of harvesting has been underestimated but research shows that its it is of relevant magnitude (Cooke & Cowx 2004). It has been shown that high exploitation

rates and selectivity in recreational fisheries may result in depensatory mechanisms, truncation of age and size structure, loss of genetic variability and evolutionary changes (Lewin *et al* 2006). It may also cause disturbances during the reproductive period, mortality of wounded fish released back to the water, pollution and introductions with negative effects (Arlinghaus & Cooke 2009). Hence, recreational fishing should be as well accounted for in management plans.

By simply introducing artificial mortality on top of natural mortality, fishing can reduce the average age and size at maturity and increase the average individual growth rate (Dunlop *et al* 2009**,** Eikeset *et al* 2009**)** in stocks because individuals that allocate high energy to reproduction relative to maintenance or growth beyond maturity, have higher fitness in scenarios where long-term survival is uncertain (Law 2007; Jørgensen & Fiksen 2010). Moreover, because some fishing gears specifically remove individuals that for example, mature when they are relatively old and big, they directly penalize the fitness of such phenotypes and therefore, reduce their frequency in the stock (Olsen *et al* 2004). Trends predicted by this logic have been observed (Swain 2007, Hutchings & Fraser 2008) and it is expected that greater fishing effort will be required to sustain the current amount of catch obtained by fishing activities from overexploited stocks (Eikeset *et al* 2013).

The gene versus environment dichotomy might be viewed as an artifact since the expression of no trait is exclusively controlled by one of the two. Rather, reaction norms, or, the expression of genotypes along environmental gradients, are what determines what phenotypes are found in a population (Dieckman & Heino 2007). However, the relative importance of each in the context of fisheries has been discussed in the way that if for example, "genes" for an old age/big size at maturity phenotype exist, removing them from a stock can have irreversible consequences for a realistic management agenda (Enberg *et al* 2009).

This would not be the case if variation in age/size at maturity is better explained as responses to environmental changes by means of phenotypic plasticity. Here, the named phenotype would be expected to reappear quickly once the selective pressure on it is released (Olsen *et al* 2004). Evidence accumulated by studying the history of some stocks indicates that it is in great part a genetic regulatory mechanism what determines

the age at maturity or the individual growth rate of fish (Olsen *et al* 2004 & Saura *et al* 2010). This implies that effective stock management plans must account for fisheries-induced selection on life history traits if desirable phenotypes that help to sustain stocks are to be preserved (Dunlop *et al* 2009).

Genetic changes induced by fisheries are not only limited to life history traits. Somewhat overlooked, behavior can play a role in determining the fitness and probability of an individual fish to get caught by fisheries (and thereby its fitness), especially when involving passive fishing gear (Uusi-Heikkilä *et al* 2008). For example, a proximate cause for a fish attacking a lure might be simply that the fish was hungry at that particular moment, an ultimate cause however is that a personality trait lead the fish to behave that way. Moreover, variation in behavioral traits such as vulnerability to angling seems to be strongly influenced by a genetic component (Sih *et al* 2004; Bell 2007; Phillip *et al* 2009 & Ariyomo *et al* 2013); therefore, behavioural traits may also evolve in response to selection regimes.

Yields obtained by fisheries might not be directly reduced by changes of the frequency of some behavioral phenotypes but these traits are also productivity-related. Stocks in which behavioral selection has occurred will have less variability to cope with environmental change due to portfolio effects (intraspecific variation protects populations from extreme fluctuations in population density (Bolnick *et al* 2003)). Their efficiency to use the resources in their distribution will diminish with the depletion of genotypes associated with personalities that make some individuals specialists in exploiting particular food items and/or zones (Wolf & Weissing 2012 & Biro *et al* 2008a).

Additionally, fisheries-induced changes in behavior can influence other phenotypic components (e.g. life history traits) via correlational selection (Biro *et al* 2008b). Some individual behaviors have a high relative importance for the social dynamics of the stocks (Couzin *et al* 2005). Finally, neglecting behavioral variability in models for population dynamics of stocks might reduce their predictive power and therefore, their convenience as tools for the designing of management strategies (Bøe 2013).

Hence, artificial selection on behavioral traits of fish has gained increasing attention. For instance, Olsen *et al* (2012) showed that in an Atlantic cod (*Gadus morhua*) population

from the Skagerrak sea, individuals with broader activity spectrums where more prone to be captured by traps, gillnets and hand lines. Meanwhile, Sutter *et al* (2012) demonstrated in laboratory conditions that recreational angling imposes higher selective pressure on bold largemouth bass (*Micropterus salmoides*) than in their shyer counterparts. These two cases illustrate how passive fishing gear can penalize the fitness of bold individuals that otherwise, are favored by natural and sexual selection respectively.

Other recent case studies, however, have reached somewhat different conclusions, indicating that more empirical and theoretical work is needed to reach a broader understanding of the nature of fisheries-induced selection on behavior. For instance, a study by Wilson *et al* (2012) found that angling targets shy bluegill sunfish (*Lepomis macrochirus*) whereas Bøe (2013) found two behavioral forms of Atlantic cod in the Oslo Fjord area that differ by their temperature preferences and their use of the water column as well as the type of fishing gears that they are captured with. More recently, Alós *et al* (2014) found increased gear avoidance in an exploited by angling population of painted comber (*Serranus scriba*) in respect to an unexploited one and Díaz *et al* (2015) found that both, active and passive gear tend to capture bolder female guppies (*Poecilia reticulata*).

A good framework for empirical studies on fisheries-induced selection on behavior is that proposed by Réale *et al* (2007). Harvest selection would require material to act on, namely behavioral variability related with reproductive success from which to select. Two variables useful to characterize variation over personality axes are willingness to attack a lure, related with the boldness-shyness axis and the latency to leave a refugee, belonging to the exploration-avoidance axis by the same authors. The first one refers to reactions in risky situations (e.g predators or humans), the second one refers to reactions towards novel situations. Both are components of individual behavior but are not necessarily related.

1.2 Objective

The general objective of this thesis was to determine to what extent recreational angling, a passive fishing technique, could impose a selection regime on a wild-caught Atlantic cod (*Gadus morhua*) population. I investigated this by quantifying fish behavior on a boldness-shyness axis, their reproductive success and their willingness to attack a lure. Specifically, I wanted to 1) test for differences in the reproductive success between bold and shy fish 2),verify if these fish were different in their explorative behavior, 3) and determine if both behaviors were linked constituting a behavioral syndrome (*sensu* Sih *et al* 2004). The working hypothesis here is that attacking fish tend to have higher reproductive success and shorter latencies to leave a refugee.

2. Materials & methods

2.1 Study species

The Skagerrak cod (*Gadus morhua*) (Figure 1) belongs to the Norwegian coastal cod group described by Møller (1969). In Skagerrak, cod lives within restricted zones that form a network of local populations separated by distances as short as 30 km (Jorde *et al* 2007). It is a highly fecund species and spawns multiple batches of offspring that remain pelagic until they reach 3-5 cm and settle in shallow areas (Kjesbu 1989 & Knutsen *et al* 2011). The juveniles grow 10-15 cm annually and mature when 2-4 years old and 30-50 cm long (Olsen *et al* 2008). This species is targeted by both recreational and commercial fisheries, being captured by a variety of methods including bottom trawls, gill nets, long lines, seine traps and hand lines (Julliard *et al* 2001). Among its natural predators are the harbor seals (*Phoca vitulina*) (Bjørge *et al* 2002) and cormorants (*Phalacroax carbo sinensis*) (Barret *et al* 1990) inhabiting the same ecosystem.

Figure 1 Skagerrak cod in artificial basin.

2.2 Study area

Fish where captured with fyke nets in the Søndeled fjord (Figure 2) located on the southern coast of Norway. This fjord system consists in three parts: Nordfjord and Sørfjord divided by the island of Barmen with only the Nordfjord having an open connection with the outer sea, and Eastfjord in the outer part. It has 30 m deep sills with sheltered basins of up to 60 m depths in the inner part and 180m in the Eastfjord. The shallow areas contain eelgrass conforming nurseries for juvenile cod whereas the deepest parts are anoxic (Dahl & Danielssen 1987). Temperature during the summer varies from >15Cº at the surface to 6Cº at 20-30m and from 0Cº at the surface to 6Cº in deeper parts during the winter.

Figure 2 Søndeled fjord map.

2.3 Measurement of variables

Fish captured with fyke nets in the Søndeled fjord area (N=65) where brought to the Flødevigen Marin Research Station, Institute of Marine Research, Arendal, and transferred to an artificial spawning basin (45 m^3). The fish were kept in the facility throughout the whole spawning season of 2014 and fed around 2 kg of frozen shrimp every day. Before placing them inside the basing each individual was tagged with an T-bar tag with an ID consisting of a letter and four numbers and a fin sample was clipped for DNA analysis purposes. A total of three variables were measured for each fish:

1. **Latency to leave a refugee** was quantified as a component of the exploration-avoidance axis. To measure the variable, an experimental set up consisting on a refugee and a new fish exploration arena was prepared (Figure 3). The refugee was a plastic box (0,7*0,4*0,6m) with a remotely controlled sliding door and the arena is a rectangular enclosure within the basin (3,5*2*1,5m) that fitted into the recording angle of a GoPro® camera located in the roof above. The fish was put inside the refugee and left be there for a 300s acclimatization period, after which the sliding door was opened. The door remained opened for 1200s while the camera was recording. During this period I quantified how long time (seconds) it took the fish to leave the refugee. Fish that did not leave the refugee at all where given a notational score of 1200s.

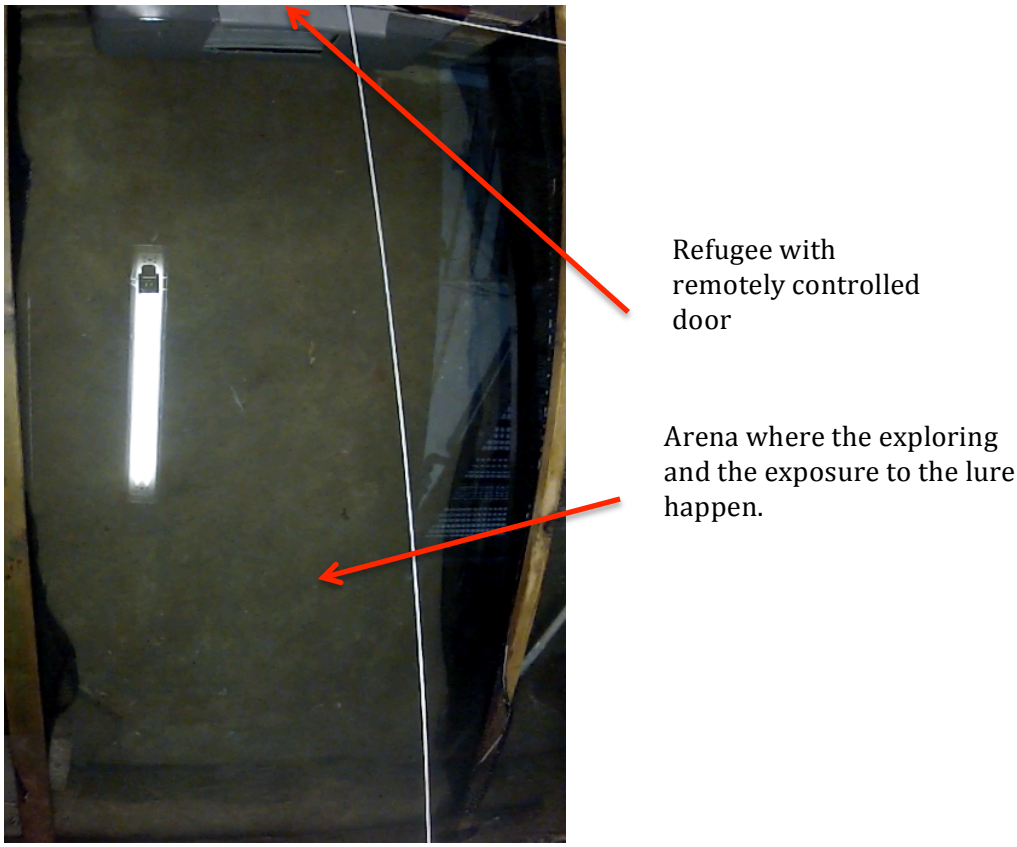

Figure 3 Set up for the measurement of the latency to leave a refugee variable.

2. **Inclination to attack a lure** was quantified as a component of the boldness-shyness axis. Groups of around 10 fish per day were placed inside the exploration arena throughout seven days. A color tag was used to identify each fish. During 1200s and while video recording, a hookless lure was introduced inside the area and moved simulating fishing by angling. An individual was considered to be bold if it bit the lure at least once during the trials. If it did not bit, it was classified as a shy individual.

3. **Reproductive success** was quantified for each fish throughout the spawning season, prior to measuring the behavioral variables (above). This was done under the assumption that selection on behavior could influence productivity by affecting fish with high number of offspring. For this purpose, an egg-collecting device (Figure 4**)** consisting on a filter within a wood structure was placed by the draining part of the keeping basin. The collector, used for around twelve hours every day throughout the spawning season, retained the eggs in a mesh. The eggs where transferred to auxiliary tanks (one per day) with fresh circulating water for hatching. Once the first fish larvae where visible, a total

of 50 of them where randomly selected and stored in RNAlater®. For each one of these, DNA extraction was performed using E-Z 96 Tissue DNA kit V-spinn extraction kit. Afterwards, a multiplex PCR with 4 microsatellite loci was performed (microsatellite loci: *GMO19*, *TCG11*, *GMO8* & *GMO35*; PCR conditions: 95Cº-5min 95Cº-30s, 56Cº-90s 72Cº-60s 72Cº-10min 4Cº-∞). A parentage analysis, which assigned each larva to its pair of parents, was performed afterwards using the software CERVUS version 3.0.

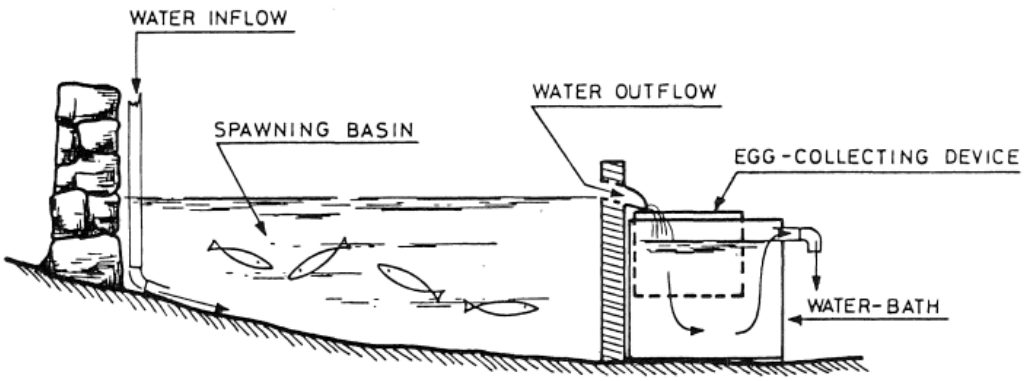

Figure 4. Egg-collecting device and spawning basin (taken from Moksness & Riis Vestergaard 1982).

2.3 Data analysis

All the data analyses were performed in SPSS® Statistics version 22. For the first objective, fish categorized as either, "bold" or "shy" to depending on whether they bit the lure or not during the trials, representing two levels of one factor (boldness) in the analyses. Tests for critical requirements of homoscedasticity (Levene 1960) and normality (Shapiro & Wilk 1965) for parametric analysis were performed for the whole sample. Given rejection of these two requirements, a nonparametric analysis of variance (Mann-Whitney *U* test (Mann & Whitney 1947)), was performed testing for an effect of boldness on reproductive success.

To analyze the relationship between the latency to leave a refugee and the boldness of fish (second and third objectives), a *survival analysis* was performed. Although originally developed for investigating the survival times of cancer patients subject to different

medical treatments, today this analysis is used other fields where it is desired to examine the occurrence of events (for example death) along a fixed experiment/study time length (Singh & Mukhopadhyay 2011). The analysis consisted of two parts.

First, Kaplan-Meier curves were graphed with boldness as a categorical variable determining latency to leave a refugee along a time axis of 1200s. To compare the generated curves log-rank, Breslow and Trone-Ware statistics were estimated.

Second, latency to leave the refugee for the fish was modeled as a response variable with the propensity to bite the lure as a categorical explanatory variable. Fish sex and size where included in this model as possible explanatory covariants as they have both been associated with personality for other fish species (see Brown & Braithwaite, 2004; Brown *et al* 2007 & Harris *et al* 2010). In this context, the specific aim of a *survival model* is to describe the probability of an event to occur during a time interval given values of certain variables. This model is described next.

Consider a *survival function*, S defined as $S(t)=\Pr(T>t)$ where t is a given time and T a random variable that denotes the occurrence of death/the event being modeled, here $S(0)=1$ always as the event can not occur at the same time as the experiment starts. A complementary function of S would be a *lifetime distribution function* or F, defined as:

$$F(t)=\Pr(T<=t)=1-S(t)$$

The later can be derivate to f, an *event density function* that would be defined as:

$$f(t)=F'(t)=(d/dt)F(t)$$

and denotes the rate of events per unit of time. A *hazard function* λ or, the event rate at time t conditional on survival until that time or later might be defined as:

$$\lambda(t)= f(t)/S(t)$$

The purpose of the *survival analysis* is to determine the effect of a given number of covariates, besides time itself, on the *hazard function*. A convenient way to do this is to

perform a *proportional hazards model* (also known as Cox regression). This survival model proposed by Cox (1972) establishes the risk of death (or the event being modeled in the particular study) as a function of time and of variables $X_1,\ldots,X_n$, each with a proportional effects on the function as follows:

$$\lambda(t,X_1,\ldots,X_n)= \lambda_0(t) \exp \sum_{i=1}^{n} \beta X_i$$

where $\lambda_0(t)$ is a basal risk (or hazard function) and corresponds to the risk of occurrence of the event when the variables $(X_1,\ldots,X_n)$ have a value of 0 and is assumed to be equal for all individuals, and the rest of the expression denotes the effect of the variables on the probability of occurrence of the event.

An advantage of from using a Cox regression to analyze data such as the latency to leave a refugee, is that it allows for incorporating incomplete subject information which is the case with for example, fish that never left the refugee during the entire duration of the experiment and where given a notational score of 1200s (these are called *right censored observations*) (Singh & Mukhopadhyay 2011)

3. Results

A total of 47 fish where assigned to the "shy" category while 18 fish were assigned to the "bold" category. Tests for critical requirements for parametric analyses of variance revealed homoscedasticity (P>0,05) (Table 1) although they also showed distributions other than normal (P>0,05) (Table 2, Figures 5 and 6) for the compared groups. The mean reproductive success was 33 larvae (shy fish: 38, bold fish: 20) the mean latency to leave the refuge was 577 s (shy fish: 540 s, bold fish 674).

	Levene's statistic	df1	df2	Sig.
Reproductive success	2,223	1	63	0,054
Latency to leave a latency to leave refugee	0,473	1	63	0,326

Table 1. Tests for homoscedasticity.

	Boldness (0 shy, 1 bold)	Kolmogorov-Smirnov			Shapiro-Wilk		
		Statistic	df	P-value	Statistic	df	P-value
Latency to leave a refugee	0	0,147	47	0,013	0,847	47	0
	1	0,299	18	0	0,776	18	0,001
Number of larvae sired	0	0,229	47	0	0,705	47	0
	1	0,25	18	0,004	0,757	18	0

Table 2. Test for normality.

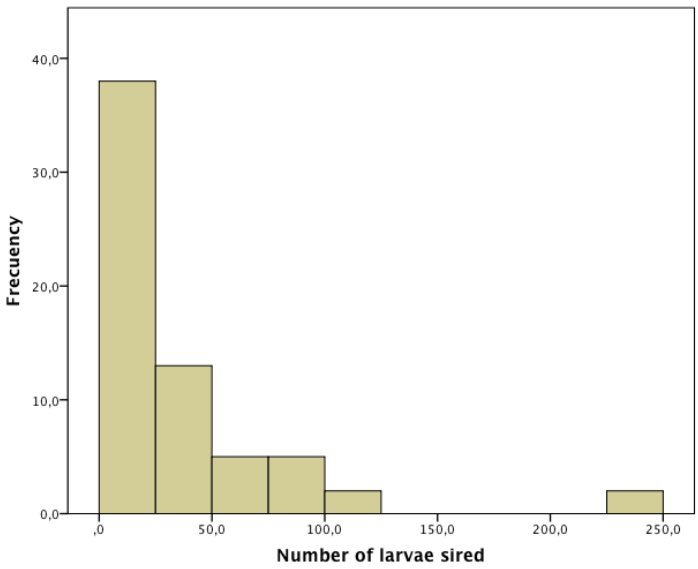

Figure 5. Distribution of reproductive success.

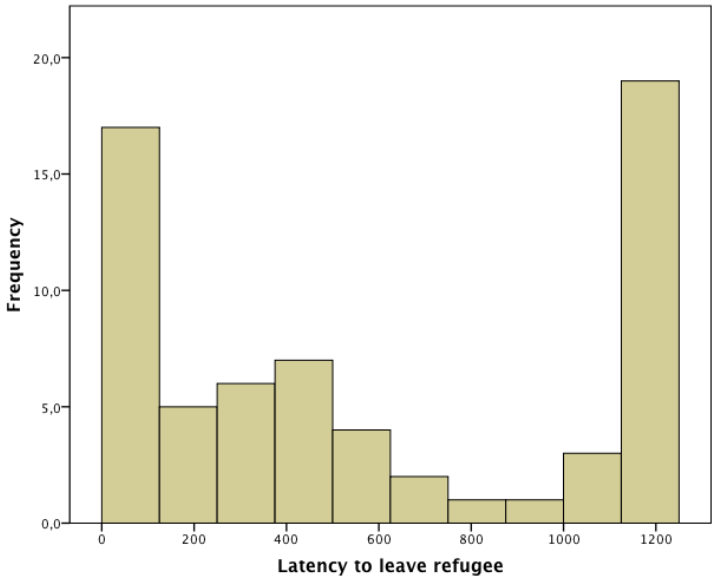

Figure 6. Distribution of latency to leave a refugee.

A non-parametric test (Table 3) for differences in the distribution of the variables revealed no difference between shy and bold fish in either latency to leave a refugee or reproductive success.

Null hypothesis	Test	P-value	Decision
Distribution of Latency to leave a refugee is the same for the categories of boldness	Mann-Whitney *U* test	0,209	Accept null hypothesis
Distribution of Reproductive success is the same for the categories of boldness	Mann-Whitney *U* test	0,359	Accept null hypothesis

Table 3. Test for differences in dependent variables distributions.

Kaplan-Meier curves (Figure 7) revealed that shy fish had a slightly higher explorative behavior defined by higher proportion of fish remaining in the refugee after the trial was finished (*right-censored observations*) than bold ones. The difference between the curves for both categories however was not statistically significant (Table 4).

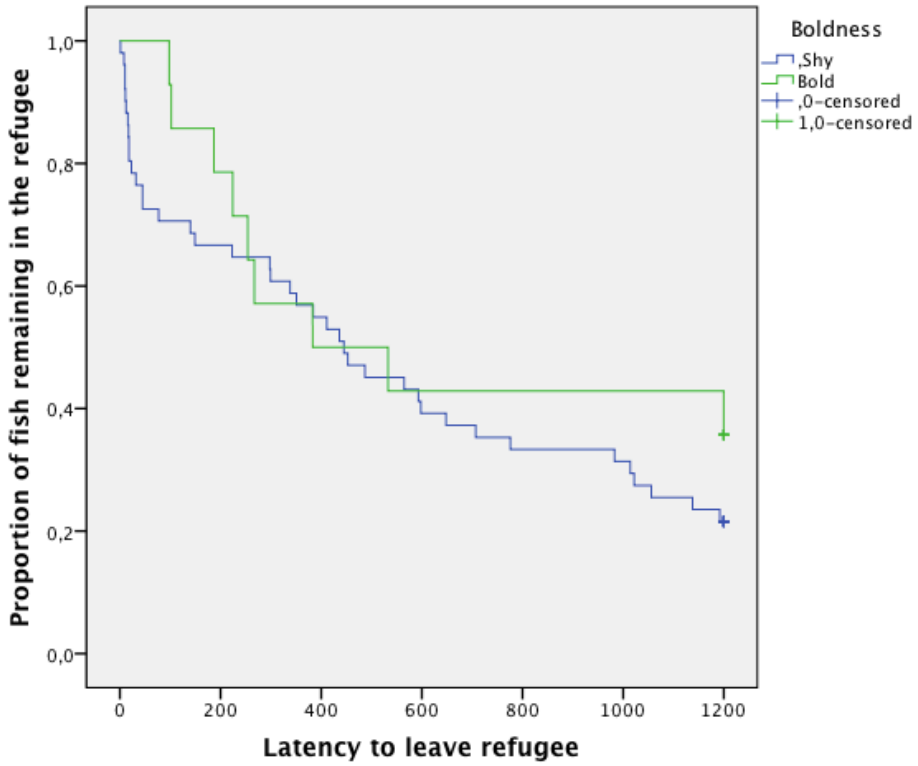

Figure 7. Kaplan-Meier curves.

	Chi-square	df	P-value.
Log Rank (Mantel-Cox)	1,845	1	0,174
Breslow (Generalized Wilcoxon)	1,342	1	0,247
Tarone-Ware	1,556	1	0,212

Table 4. Overall comparisons of survival curves.

The *proportional hazards model* did not fit the data as expected (P>0,05) and this did not change with the inclusion of the categorical variables, boldness and sex, plus size as neither of them had a significant effect on the probability of a fish to leave the refugee (Table 5)

Omnibus test of model coefficients

-2 Likelihood	Overall			Change from previous step			Change from previous block		
	Chi-square	df	Sig.	Chi-square	df	P-value	Chi-square	df	P-value.
354,904	2,421	3	,490	2,543	3	,468	2,543	3	,468

Variables in the ecuation

	β	SE	Wald	df	P-value	Exp(*β*)	95.0% CI for Exp(*β*)	
							Lower	Upper
Boldness	,450	,356	1,604	1	,205	1,569	,781	3,149
Size	,002	,003	,492	1	,483	1,002	,996	1,009
Sex	-,128	,305	,176	1	,674	,880	,483	1,601

Table 5. Model parameters for Cox regression (latency to leave a refugee).

4. Discussion and conclusion

¿Is there a relationship between recreational angling, vulnerability to fishing and reproductive success in Atlantic cod (*Gadus morhua*)? This thesis used an experiment to answer that question. No relationship between the variables mentioned was detected Potential causes for this outcome are discussed as follows. Additionally, suggestions on how to perform future experiments aiming to answer the question are proposed.

The results found are somewhat contrary to studies in which a positive correlate between reproductive success and boldness has been detected (Sutter *et al* 2012) as well as a negative one (Wilson *et al* 2010). However in the first case the species, largemouth bass (*Micropterus salmoides*), exhibits intensive parental care whereas in the second, the Eastern mosquito fish (*Gombusia holbrooki*), has internal fertilization. Atlantic cod (*Gadus morhua*) on the other hand is a broadcast spawner. Thereby, sperm competition

(Stockley *et al* 1997 & Bekkevold *et al* 2002), agonistic interactions between males and mate choice on the basis of size (Hutchings *et al* 1999 & Rowe *et al* 2008) might be of greater importance for its reproductive success than variables like exploration and boldness.

Similarly, fish categorized as bold did not exhibit more explorative behavior as evidenced by shorter latencies to leave the refugee. Although this is contrary to the working hypothesis it might be expected from a population in which intensive fishing has occurred for centuries. This type of exploitation might have made fish evolve to a particular state of exploration shared by all the individuals used for this experiment. Less- or non-exploited cod populations should exhibit a wider range of behavioral variability since selection would not be acting on them. Behavioral comparisons between fish from both kinds of habitats (e.g. the study area and marine protected areas) might shed light on this.

Besides boldness, the *proportional hazards model* used in this study also considered the effects of sex and body size on exploration as each has been related with behavior of other fish species (Brown *et al* 2007 & Harris *et al* 2010). However, no significant effects were found in my study. An additional variable not analyzed here that could explain the observed distribution of the latency to leave a refugee variable is individual growth rate. Individuals with rapid growth rates have been shown to increase appetites, which in turn are related with augmented foraging activity and boldness, which would make them more prone to encounter fishing gear (Biro *et al* 2008a). Therefore it would be expected that these individuals had more explorative behaviors.

Ethological studies in fish (Bell *et al* 2009) and other vertebrates (Van Oers *et al* 2004) often include repeatability tests of individual differences in behavior. Although these were not performed in this study, an assumption was that in the context of fisheries, behavior is determined by a genetic component and therefore is consistent in an individual basis. Repeatable behavior has been documented for a number of species and populations, including the Skagerrak cod (Ariyomo *et al* 2013, Phillip *et al* 2009, Olsen *et al* 2012). Therefore, lack of repeatability tests would not necessarily affect the inferences from the results presented here.

A constraint of this study is the lack formal treatments for the evaluation of exploration, for example, different breed lines representing clearly defined levels of behavior towards a lure. Similarly, this study uses fish from only one population in which positive selection for low catchability by angling might have already occurred. Given logistic difficulties to breed different lines of Atlantic cod (compared to other species such as largemouth bass), I suggest that future experiments take advantage of the widespread distribution of cod across both, exploited and protected areas. This may represent a natural experiment that could provide insights into the nature of behavioral evolution by means of angling pressure.

Another potential weakness of this experiment is that all fish where caught using fyke nets, a passive fishing gear where captures depend on the activity of the fish. This might have induced a bias in the way that some of the variability in personality traits could have been left out and thus the sample used may not be representative for the population as a whole. Wilson *et al* (2011) overcame this limitation by using a combination of both passive (angling) and active (seine net) fishing gears. Further studies on cod behavior in relation to fisheries might benefit from this practice.

Alós *et al* (2015) studied painted comber (*Serranus scriba*) exploited by angling and found spatial variation in fish personalities with increased gear avoidance in the heavily exploited areas. However, they could not tell apart two plausible explanations: learning and fisheries-induced evolution mediated by genetic change (maternal effects, an experience might be important as well (Réale *et al* 2007)). Either mechanism is responsible; differentials in the reproductive success between individuals with contrasting behaviors towards fishing gear would set a basis for selection to act on. My study did not find such differences between the shy and bold categories defined. However, this could be the an artifact related with the sample size.

My experiment used the framework provided by Réale *et al* (2007) to assess behavior. That is, latency to leave a refugee as a component of the explorative-avoidance axis was measured in a new environment whereas vulnerability to angling, a component of the shyness-boldness axis, was measured afterwards in the same environment thus controlling for the novelty factor. However, Réale *et al* (2007) proposed other axes that might be related with selection on behavioral traits: activity, aggressiveness towards

conspecifics and sociability, none considered here. Moreover, they suggest that personality traits should be distinguished from motivational and ability states such as hunger level and cognitive ability. The consequences of omitting the later in my experiment are unknown.

Finally, another potential limitation might be that my experiments where conducted right after the spawning season finished. The condition factor, which varies greatly throughout the spawning season with a tendency to decrease towards the end of it (Lambert & Dutil 2000) has been shown to influence reproductive success (Raktikin *et al* 1999). This sort of relationship might extend to alterations in post-spawning behavior given lower energy levels. Such association could have affect the variables tested here in the way that fish could have had reduced activity during the experiment period.

This experiment constitutes one of the few efforts to understand possible evolutionary consequences of behaviorally selective-harvesting in a marine fish species of commercial interest. Overall, no significant relationships between two behavioral variables related with fisheries and reproductive success were detected. This suggests absence of behavioral syndromes as defined by Sih *et al* (2007) or behavioral selection. A possible reason for the later is lack of variability in the sample (which in turn could be the result of using only one fishing method to capture the tested individuals) or in the population (if after exploitation, evolution towards certain behaviors has already occurred). Further studies should perform a similar analysis using fish from both exploited and protected areas, captured with a variety of fishing methods including passive and active gear. This will ensure that most of the behavioral variability is encompassed allowing for detection of possible relationships not evident here as well as more robust inferences.

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